

# **Coastal Aerosol Study, Duck North Carolina, ONR (CASCO)**

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## **LONG TERM GOALS**

The long-term goals of the research are to understand and assess the effects of the atmosphere on the detection of targets at low altitudes over sea in coastal regions with LR-IRST systems. Effects considered are transmission losses due to aerosols and water vapor, effects of turbulent fluctuations of the air temperature on blurring and scintillation, and the effect of the vertical temperature gradients on IR refractivity.

## **OBJECTIVES**

The objectives of the research performed in the framework of the present grant are to further analyze and validate results obtained in the EOPACE experiments on the Californian coast, in particular:

- to validate the aerosol source function in the surf zone;
- to quantify the effect of the surf zone on the aerosol concentrations in the coastal atmosphere, in relation to surface-produced sea spray aerosol and anthropogenic aerosol;
- to determine the turbulence and refractivity in the inhomogeneous coastal boundary layer and their effects on imaging of low altitude point targets;
- to improve the description of the aerosol size distribution as function of height and meteorological parameters.

## **APPROACH**

Data from the EOPACE IOP's (1-8) in 1996-1998 are further analyzed and interpreted.

During the EOPACE experiments in Duck, North Carolina, aerosol particle size distributions were measured at three levels at the base of the pier. From comparison with particle size distributions measured at the end of the pier by the group of Prof. Mike Smith from the University of Sunderland (UK), surf-aerosol source functions will be derived. The results will be compared with those obtained at the Californian coast. In addition, lidar measurements were made on the aerosol plumes generated by waves breaking in the surf zone.

A Coastal Aerosol Transport model (CAT) was developed by Dr. Vignati, presently at Joint research Center in Ispra (Italy) with data from the EOPACE Surf efforts. To validate the model, a boat was equipped with optical particle counters, a sonic, a lidar system and meteorological instrumentation to

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obtain data on the evolution of the aerosol size distributions and the coastal atmospheric boundary layer in off-shore winds.

The boat was further equipped with infra-red sources to derive atmospheric propagation properties such as transmission, scintillation and refraction, as function of fetch, from data collected with thermal imagers by Ir. De Jong (TNO-FEL) and other EOPACE participants.

## WORK COMPLETED

The Coastal Aerosol Transport model (CAT) has been further developed and applied in some simulations to determine the effects of surf-produced and anthropogenic aerosols on the aerosol content in the coastal atmosphere and simulations were made of heterogeneous reactions between nitric acid ( $\text{HNO}_3$ ) and sea spray aerosol. CAT was further used to simulate the surf plumes measured with lidar in the Duck 1998 experiments. This work was carried out by Dr. Vignati (presently JRC, Ispra, It), in the framework of her PhD work completed in March 1999 with the thesis defense, and in cooperation with Dr. Berkowicz (NERI, DK) and myself. The work on the surf plumes is continued by Dr. Vignati and myself in cooperation with Dr. Hooper (NRL) and Dr. Gathman (SPAWAR).

The boat measurements in connection with the Duck 1999 measurements were designed to validate CAT for transport over fetches of up to circa 25 km. Due to the weather, only four cruises could be made. The results are being analyzed, both for the evaluation of CAT and for the evaluation of the atmospheric propagation measurements. The latter effort is in cooperation with Ir. De Jong of TNO-FEL.

Because the weather did not allow to sail the boat as frequently as planned, in the second part of the Duck experiments, when the NRL lidar failed, the TNO lidar was moved to the pier to measure plumes of surf-produced aerosols, with both horizontal and vertical scans. Results are partly evaluated.

The Duck aerosol measurements were successfully completed and a start has been made with the evaluation of the results.

## RESULTS

The analysis of the Californian surf measurements has been completed and an empirical relation describing the surf source function for wind speeds up to  $9 \text{ m s}^{-1}$  has been suggested:

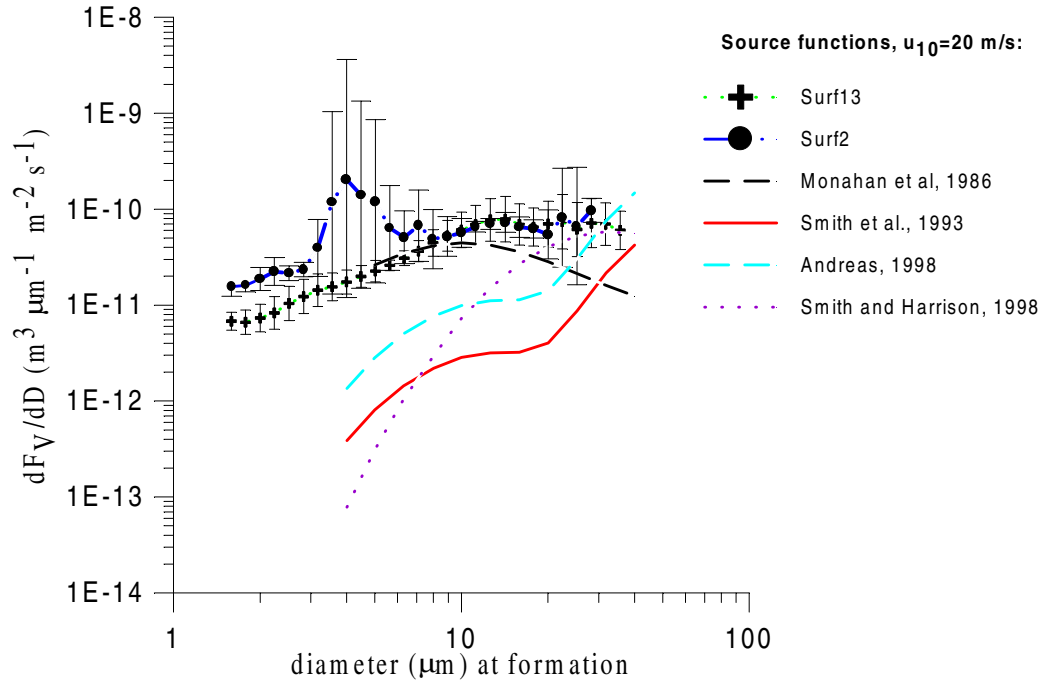
$$dF_N/dD = 1.1 \exp(0.23 u_{10}) D^{-1.65}, \quad (4)$$

where  $F_N$  is the surface flux ( $\mu\text{m}^{-1} \text{ m}^{-2} \text{ s}^{-1}$ ),  $u_{10}$  the reference wind speed at a height of 10 m and  $D$  the particle diameter at formation. This simple model applies to particles with diameters between 1.6 and  $20 \mu\text{m}$  at formation.

The surf source functions derived from data collected in La Jolla (Surf13) and in Moss Landing (Monterey Bay) are shown in Figure 1. The data in Figure 1 are normalised to a whitecap cover of 10.5%, i.e. a wind speed of  $20 \text{ m s}^{-1}$ . Also shown are current source functions that apply for the open ocean in a wind speed of  $20 \text{ m s}^{-1}$ . The comparison suggests that the Monahan et al. [1986] source function, taking into account only the bubble part and not the production of spume drops, is a good

representation for the flux of particles up to circa 10  $\mu\text{m}$ , whereas Smith and Harrison [1998], and perhaps also Andreas [1998], seem to better describe the flux of larger particles. However, it is noted that oceanic whitecaps have physically different origins than waves breaking in the surf, and thus the comparison of surf source functions and production from breaking waves on the open ocean must be carefully interpreted.

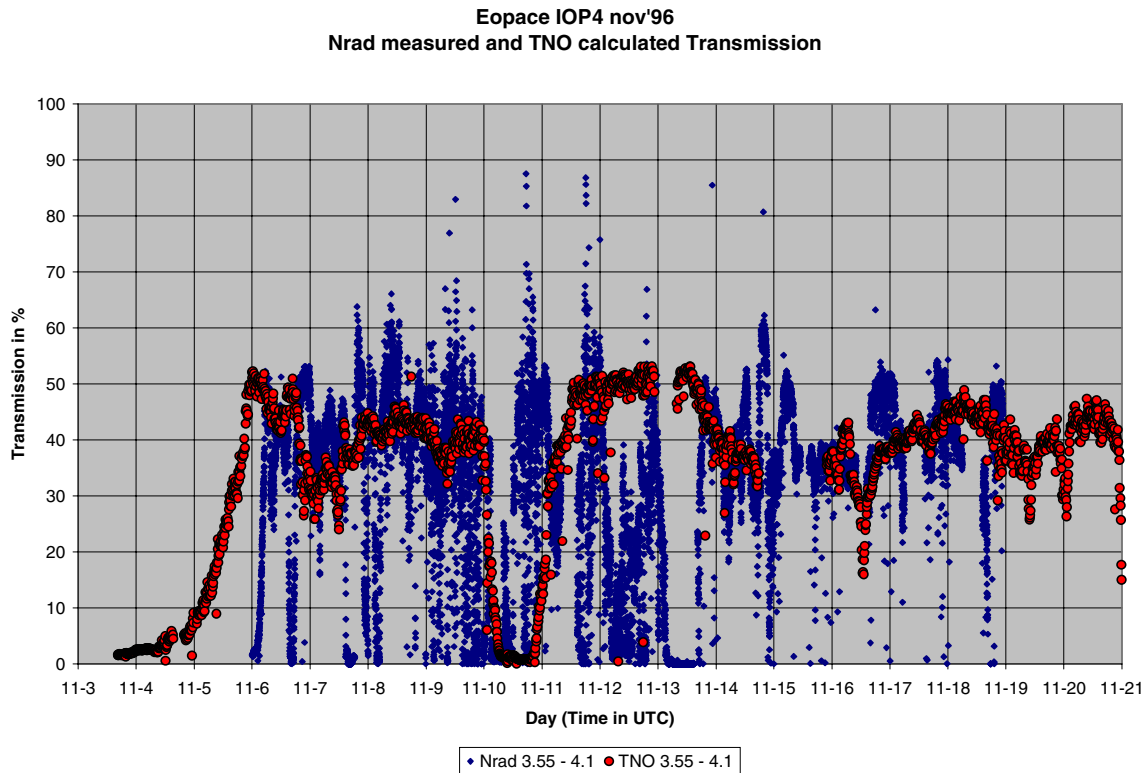
A publication on the surf results has been prepared for submission in November.



**Figure 1. Source functions for sea spray aerosol produced over the surf (normalised to a whitecap cover of 10.5 %) and at the open ocean at a wind speed of 20 m/s. The surf zone aerosol source functions were derived from the Surf-1,3 (La Jolla) and the Surf-2 experiments (Moss Landing, Monterey Bay) and multiplied by 0.105 to account for the assumed whitecap cover of 100% in the surf. The oceanic source functions of Monahan et al. [1986], Smith et al. [1993], Andreas [1998] and Smith and Harrison [1998] were evaluated for a wind speed of 20 m/s (i.e. whitecap cover of 10.5 % [Monahan and O’Muircheartaigh, 1980]).**

During EOPACE experiments in 1996 and 1997, transmission was measured across San Diego Bay, along an over-water path of 15 km by TNO-FEL and over a 7 km path by Dr. Zeisse from SPAWAR (San Diego). TNO-FEL also measured aerosol particle size distributions at the end of the 15 km path. The data are analyzed in a common effort lead by Dr. Zeisse. An example of initial results is shown in Figure 2, where the transmission along the 7 km path calculated from measured aerosol size distributions combined with MODTRAN calculations of molecular effects, using current meteorological parameters, is compared with the measured transmission, both for the 3.55-4.1  $\mu\text{m}$  wavelength band. The calculated transmission compares favorably with the mean experimental data. Fluctuations around the mean are ascribed to turbulence and refraction effects, which are further analyzed in cooperation with Prof. Davidson (Naval Postgraduate School, Monterey) and Dr. Zeisse (SPAWAR).

The transmission data show daily variations that are ascribed to the sea breeze effect. Comparison with the meteorological data shows that in off-shore wind the transmission is much higher than in on-shore wind, likely due to contributions from the surf-produced aerosol in off-shore wind. Effects of aerosol advected from land (anthropogenic and natural) are further investigated, as well as other effects on the coastal transmission. Data from the 15 km path and other wavelengths than the 3.55-4.1  $\mu\text{m}$  band are used in this analysis, as well as data from other EOPACE experiments in San Diego and in Monterey.



**Figure 2.** Time series of measured (+, indicated as Nrad) and calculated transmission (red circles, indicated as TNO) in the 3.55-4.1  $\mu\text{m}$  band, along the 7 km path across San Diego Bay, November 1996 (EOPACE IOP4). The calculated transmission is from aerosol data measured on Imperial Beach Pier, and MODTRAN molecular calculations using concurrent meteorological observations.

## IMPACT

The results can be used to assess the effects of the atmosphere on the performance of thermal imagers over sea, and in particular the performance of LR-IRST systems. The surf-produced aerosol affects atmospheric processes involving sea spray particles, such as heterogeneous reactions, at fetches of at least 10 km in off-shore winds. Sea spray also has a variety of influences, both inland and over sea, e.g. on ecosystems.

## TRANSITIONS

The EOPACE results of TNO-FEL will be exchanged with other EOPACE participants, to lead to a common analysis effort combining all required expertise to achieve the EOPACE goals.

## RELATED PROJECTS

The efforts described above are in conjunction with other projects addressing electro-optical propagation over sea, in part basic research, in part applied research. The EOPACE efforts will take place in conjunction with EOPACE efforts funded by the Netherlands Ministry of Defense, including work on long-range transmission, IRST and backgrounds. Data from other areas, e.g. the North Sea, the North Atlantic, the Mediterranean and the Baltic, are from other projects supported by the Netherlands Ministry of Defense, the EU or other funding agencies.

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